DESIGN OF AN ALGORITHM FOR OPTIMUM ROUTE SELECTION FOR BUSES IN DEMAND RESPONSIVE TRANSIT SYSTEMS

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ABSTRACT: *The major aim of this paper is to devise optimum routes for buses in demand responsive transit systems to reduce the overall ride time of passengers on the bus stops. The routes of the buses in such systems are not fixed which enables buses to change their routes according to the demands of the passengers. Making the routes of the buses flexible will not only reduce the wait time of passengers on the bus stops but also reduce the ride time of the passengers in the buses. While reducing the wait time and the ride time of the passenger is important; it is also essential to keep the overall cost of the system minimal. This paper will focus on the design of an algorithm that reduces the overall ride time of the passengers in the buses while keeping the wait time of the passengers on the bus stops and overall cost of the system minimal.*

KEYWORDS: Demand Responsive Transit, Intelligent Transportation Systems, Vehicular Ad-hoc Networks, Flexible Bus Systems, Wireless Technologies

INTRODUCTION

In today's world, innovation and change is the most important aspect of the technology. It is playing an essential role in all the fields of life by improving the methods of performing various tasks. Transportation is one of the major tasks performed every day. With the increase in the population, vehicles on roads are increasing immensely. In order to improve the transportation standards, technology is playing a vital role. Smart and efficient transportation systems are being developed throughout the world to increase safety and comfort for drivers on road. Such systems are called Intelligent Transportation Systems (ITS). One of the key branches of ITS is Demand Responsive Transits (DRT) that deals with the public transportation system. In DRTs public transports travel based on the demands of the passengers. They do not have any fixed route or schedule.

This paper deals with a special type of DRT called Flexible Bus Systems (FBS) in which bus routes are not pre-scheduled and hence can be changed according to the demands of the passengers. In FBS, special bus stops are used which are referred to as Intelligent Bus Stops. These Intelligent Bus Stops have the capability of communicating with the buses using a short range wireless technology standard, ZigBee (IEEE 802.15.4) [1].

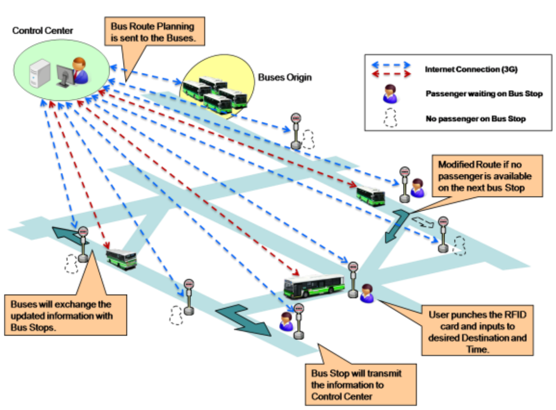

Fig. 1: Model of Flexible Bus Systems

Fig. 1 illustrates the model of FBS. As illustrated in the figure above, in FBS, all the bus stops (Intelligent Bus Stops) are connected to the central hub called Control Centre through wired or wireless internet connection. As soon as passenger reaches the bus stop, he enters his destination. This information is transmitted to the Control Centre which then requests the Bus Stops to transmit the information of available passengers on the Bus Stops to the Buses. Each Bus is connected to each Bus Stop in the system through ZigBee. Whenever a Bus reaches the range of the Bus Stop; all the information received from the Control Centre is transferred to the Bus. This makes buses and bus stops aware of all the passengers' available on the bus stops.

In order to improve the efficiency of the system, FBS aims at reducing the wait time of the passengers on the bus stops and ride time of the passengers in the buses. Although wait time and ride time of the passengers can be reduced by increasing the number of buses in the system but it will significantly increase the overall cost of the system which would be unaffordable for developing countries.

This paper is aimed at reducing the ride time of the passengers but still keeping the overall cost of the system minimal which will make it affordable for developing countries as well.

The remainder of this paper is organized as follows: Section 2 presents an overview of the related work. Section 3 discusses the proposed system model, identifying the problem scenario, the detailed design, implementation of the proposed algorithm. While the evaluation parameters, simulation results and discussions are elaborated in section 4 and finally concluding remarks are mentioned in section 5.

RELATED WORK

Plenty of researchers have touched the different horizons of Demand Responsive Transits (DRT) talking about multiple interdependent parameters of Flexible Bus System (FBS) that severely affect the performance of an algorithm. Some of the most appropriate aspects of the domain are discussed here.

ZigBee is among the favourite technologies now a day for communication purposes in DRTs. Razi [1] have introduced ZigBee as a communication technology for communication between buses and bus stops that are connected to the control centre. Control centre, being a centralized entity, is the brain of the whole system. They have shown from the experiments that usage of ZigBee as a communication technology has reduced the cost of the overall system at the great extent.

Scheduling of buses in DRTs is also one of the important aspects to be dealt with extreme care. Dessouky [2] have emphasized on the real time scheduling rules for the vehicles in demand responsive transit. They have presented a new heuristic for real time scheduling of such systems based on the detailed literature review of the current state of the art in the domain that aimed at maximizing the ridesharing while offering best services. They have finally evaluated their heuristic using data obtained from para-transit service providers in Los Angeles and showed better performance of their approach.

The productivity of operating practices in demand responsive transit is also one of the significant areas of research. Quadrifoglio [3] contributed to work on the productivity aspects of specific operating practices that are widely implemented by DRT providers. They noticed the effect of zoning vs. non-zoning strategy and time window settings on different performance measures like total trip miles, deadhead miles and fleet size. They constructed a simulation model of the operations for the DRT providers based on data of DRT in a specific countryside. Their results explore the existence of linear relationships between operating practices and performance measures.

The total trip time is also among the significant parameters of DRTs. Uehara [4] have suggested a new transport system where passengers in suburbs can commute to passengers in major urban areas by using new demand responsive buses reducing traffic congestion. This sort of cooperation between transport modes can greatly reduce the total trip time of the passengers. Their simulation results showed the clear difference in the trip time by using this system as compared to existing demand responsive systems.

Multi agent based demand responsive transit systems can also play their role optimally in Flexible bus systems. Xu [5] have proposed a multi agent based DRT service model adopting a practical multi agent planning approach that comes up to the requirements of today's DRTs aimed at minimizing the riding time, waiting time, trip time for buses that's too using minimum number of vehicles. In this model, an agent representing a vehicle locally searches for the best route in cooperation with other agents of the system. The experiment results showed the superiority of their proposed method as compared to other models.

Cost effectiveness of the demand responsive transits is one of the major concerns of the day as with such a great increase in number of mobile devices used for DRT, it is essential to investigate the financial aspects for developing this sort of systems. Thompson [6] has determined the financial viability of DRTs. They have formulated a model for estimating the feasibility of implementing this kind of systems that involved investigating whether these systems can achieve an optimum level of acceptability at affordable costs.

PROPOSED SYSTEM MODEL

The aim of the model proposed in this paper is to improve the efficiency of FBS by reducing the ride time of the passengers and still keeping the overall cost of the system minimal. Fig. 2 below shows the proposed model studied in this research article.

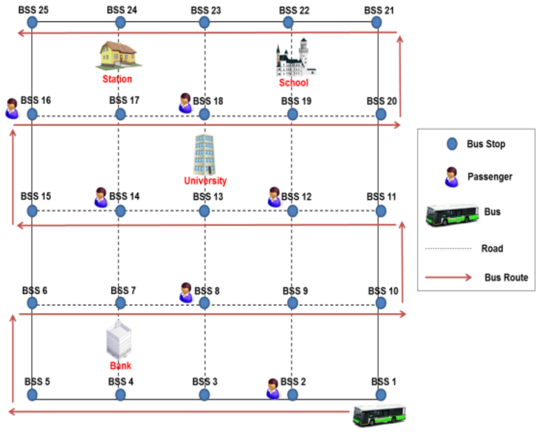

Fig. 2: Proposed model for study of optimum route selection for buses in FBS

As illustrated in Fig. 2, the model is a 5x5 matrix in which neighbouring bus stops are connected to each other in such a way that bus can take a route to that bus stop if required. For example, bus stop 2 (BSS 2) is connected to both bus stop 3 (BSS 3) and bus stop 7 (BSS 7).Each bus in FBS is initially assigned a route and a schedule which can change depending upon the demands of the passengers. Bus route is illustrated by red arrows in Fig. 2. Each bus has a certain capacity. For the purpose of this research the capacity of the bus is kept as a constant to 10, which means total numbers of passengers which can ride a bus at a time are 10.

The model is designed in such a way that passenger source and destination are bus stops. Each passenger has to come to bus stop to ride the bus. Similarly, each passenger can get off at only the bus stops. Furthermore, destinations like School, University, Station and Bank are close to bus stops and passengers desiring to go to these destinations are required to get off the bus at the closest bus stops, e.g., a passenger desiring to go to University will have to get off the bus at BSS 13 as shown in Fig. 2.

PROPOSED SYSTEM FLOW

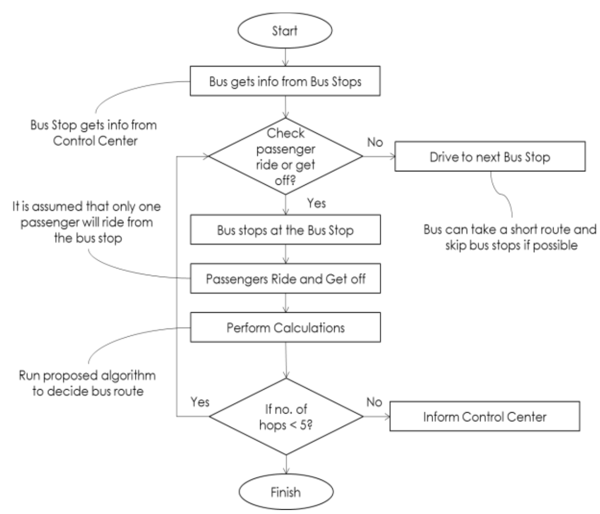

Fig. 3: Proposed System flow

Fig. 3 above illustrates the proposed flow of the system for studying optimum route selection for buses in FBS. Initially bus is assigned a scheduled route (BSS1 → BSS25) as shown in Fig. 2. However as soon as the passenger arrives at the bus stop, this information is transferred to the bus and hence bus can change its default route. As mentioned earlier, the information of the passenger is transferred to the bus through bus stops. Each bus stop will get the information of the passengers through the control centre. Before reaching a bus stop, the bus checks if there is any passenger to get off or ride to and from this bus stop. If no, the bus will move to the next bus stop. If yes, the bus will stop at the bus stop. Passenger will ride and get off the bus. While bus is at the bus stop, calculations for the bus route will be performed. These calculations involve running proposed algorithm (explained in the next section). One of the important aspects of the calculation is to check the no. of hops required to take the passenger to the destination. If hops are more than 5, that passenger will be asked to ride another bus through Intelligent Bus Stops. However, if the hops are less than 5, the whole process will be performed again.

PROPOSED ALGORITHM

In order to reduce the ride time of the passengers in the buses, an efficient algorithm is devised in this paper. The algorithm best works with 5x5 matrix in which maximum number of hops cannot be more than 5. If ride time of the passenger exceeds 5, different bus will pick up the passenger and drop him to his desired bus stop.

$$\sum_{i=1}^{k} N_{ik} = N_1 + N_2 + N_3 \dots N_k \quad (1)$$

Equation 1 is used to calculate total number of hops from one bus stop to another for a passenger riding the bus. In Equation 1, sum of N_{ik} is the total number of hops from bus stop 1 to bus stop k, where k = 25 in Fig. 2. N_1 to N_k are the hops for each bus stop from bus stop 1 to 25.

$$\sum_{i=1}^{k} RT_{(p_i)_{i\to k}} = T_{1\to 2} + T_{2\to 3} \dots T_{k-1\to k} \quad (2)$$

Equation 2 calculates the total ride time for the passenger from his riding bus stop to his destination. In equation 2, $RT_{(p_i)_{ik}}$ is the riding time of the passenger from his riding bus stop to the destination. $T_{1\to 2}$ is the time taken by the bus from bus stop 1 to 2. Similarly, $T_{2\to 3}$ is the time taken by the bus from bus stop 2 to 3 and so on.

In this proposed algorithm, total capacity of the bus is kept constant at 10 which mean each bus can occupy maximum of 10 passengers at a time. Similarly, it is assumed that each bus stop will have only one passenger to ride. One of the limitations of this system is that each passenger has to go to the bus stop to ride the bus instead of bus going door to door for picking up the passenger. Similarly, each passenger will be dropped at the nearest bus stop of passenger's desired destination instead of dropping the passenger exactly to his destination.

SIMULATION RESULTS

Several simulations were performed to gauge the efficiency of the proposed algorithm. Results were encouraging and help in optimum route selection for buses in demand responsive transit. Since this paper only deals with the ride time of the passengers, so proposed algorithm is devised in a way that it only optimizes the ride time of the passengers in the buses.

According to Fig. 2, a passenger is available on BSS2. Let's call that passenger P1. Assuming the destination of the passenger is University, near BSS13. Let's call that destination D1. Although the schedules bus router is from BSS1 → BSS 25 but since the routes of the buses are flexible so they can change as per the demand of the passenger. Below are the calculations for the ride time of the passenger P1 based on our proposed algorithm:

$$P1 \rightarrow D1 \quad \text{(i)}$$

$$BSS2 \rightarrow BSS3 \rightarrow BSS8 \rightarrow BSS13 \quad \text{(ii)}$$

$$\sum_{i=1}^{k} N_{ik} = 3 < 5 \quad \text{(iii)}$$

$$\sum_{i=1}^{k} RT_{(p_1)_{1\to 3}} = 3 \quad \text{(iv)}$$

In above calculation, (i) illustrates that passenger P1 wants to go to destination D1; (ii) describes the proposed route that bus will opt to drive the passenger to his destination; (iii) illustrates that total number of hops will be 3 for the bus to drive from bus stop BSS2 to BSS 13 and since it is less than 5 so bus can pick this passenger and drop to his destination; (iv) illustrates the total ride time of the passenger from his riding bus stop to his destination which in this case is 3 provided each hop has a time cost of 1.

Based on above calculations, several simulations were performed for various arrangements. Fig. 4 illustrates the results based on calculations made for model presented in Fig. 2. As shown in the figure, the proposed algorithm significantly reduces the ride time of the passengers in the buses.

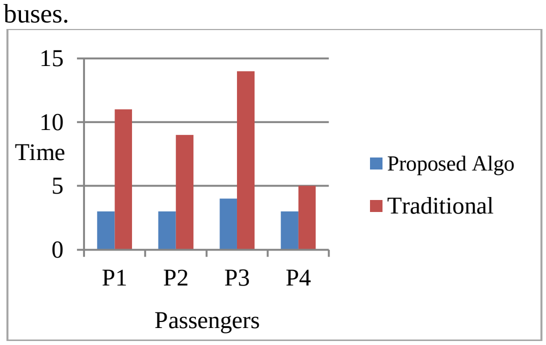

Fig. 4: Simulation results for 4 passengers

Various simulations were performed by increasing the number of passengers in the bus. A total of 10 numbers of passengers were ridden in the bus and efficiency of the proposed algorithm was measured. The results were excellent since each passenger was dropped to his desired bus stop earlier than the in traditional model. Fig. 5 below shows the simulation results for 10 passengers along with their riding time using proposed algorithm and the traditional mechanism.

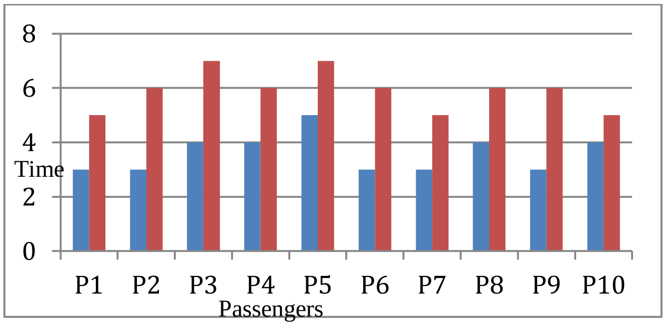

Fig. 5: Simulation results for 10 passengers

CONCLUSION

The paper proposes an algorithm for optimizing the riding time of the passengers in the buses in a specially designed Demand Responsive Transit called The Flexible Bus Systems. In this system the routes of the buses are flexible and buses can change their routes depending on the demands of the passengers. The devised algorithm works with a 5x5 matrix in which number of hops from the source to destination of the passenger is checked against a constant 5. If hops are less than 5, the bus will pick up the passenger else it will inform the control centre to request another bus to pick up the passenger. Similarly, the algorithm makes sure that it will only allow the bus to pick up the passengers that do not significantly affect the ride time of the passenger in the bus. Simulation results show that the proposed algorithm performs well for maximum of 10 passengers per bus which is actually the maximum capacity of the bus for this specific paper.

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